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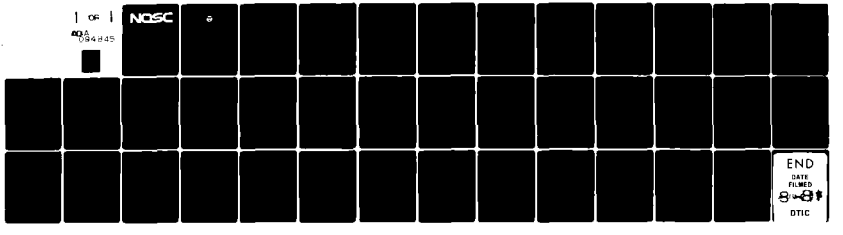

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Technical Report 542

A SURVEY OF THE SPINY LOBSTER *(PANULIRUS INTERRUPTUS)* POPULATION IN SAN DIEGO BAY, CALIFORNIA

An Impact Study of Pier Construction Activities

H.W. Goforth, Jr. and S.C. U'Ren

15 April 1980

Final Report: March-July 1979

Prepared for
Naval Facilities Engineering Command

Approved for public release; distribution unlimited

NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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Recent pier construction activity in San Diego Bay necessitated an evaluation of its impact on the spiny lobster (Panulirus interruptus). Lobster movements were monitored by placing standard commercial lobster traps at sixteen selected stations in San Diego Bay. Various data were recorded and lobsters were tagged and subsequently released. This report documents the findings of the study.

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SUMMARY

OBJECTIVE

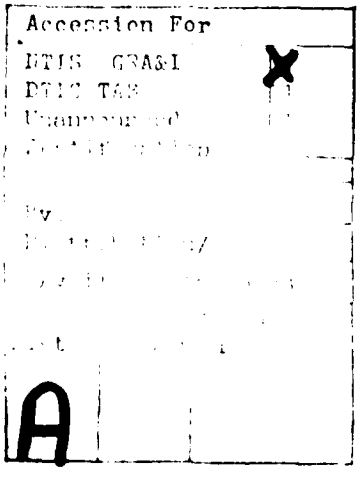
To monitor the movements of San Diego Bay lobsters (Panulirus interruptus) during the spring months and assess possible impact of dredging and construction activities upon their suspected inward seasonal movement.

RESULTS

Results were compared to a previous study conducted during the same season, but in 1977, prior to pier construction. Although the lobster catch in the immediate construction area was significantly reduced, lobsters did not appear to be deterred from moving past or entering the construction site.

RECOMMENDATION

Based upon the results of the study and additional data presented in this report, there appears to be a seaward movement of female lobsters in late summer and early fall. A well-designed full-year study with concurrent sampling inside and outside the bay is recommended to determine if such a pattern exists.



CONTENTS

EXECUTIVE SUMMARY

San Diego Bay provides a habitat for a significant population of California spiny lobsters (Panulirus interruptus) that is protected from commercial trapping. However, this population mixes with the adjacent coastal lobster population which supports a commercial fishery. The seasonality, significance and degree of mixing between the two populations have not been adequately documented. Additionally, only fragmented data are available describing the population structure and reproductive cycles of the San Diego Bay lobster population.

The purpose of this study was to monitor the movements of the San Diego Bay lobsters during the spring months and assess the possible impact of dredging and construction activities upon the suspected inward seasonal movement of lobsters. Since construction activities were located near the entrance to the bay and adjacent to known lobster habitats (i.e., eelgrass beds and subtidal riprap), environmental agencies were concerned whether this might create a barrier to the lobster movements required for successful reproduction and hence adversely affect the lobster fishery. Due to the paucity of data to reliably predict the degree of impact, this study was conducted concurrently with pier construction.

The results of this study were compared with those of a previous study conducted during the same season in 1977 prior to pier construction. Pier construction activities were found to significantly reduce the lobster catch in the immediate construction area compared to the preconstruction study and adjacent areas during this study. However, construction and dredging did not prevent lobsters from entering or moving past the construction site. Female lobsters representing all reproductive conditions were captured within the

construction site, albeit in reduced numbers, they were in representative ratios. Mean turbidity levels at the construction site were not significantly higher than those measured at other San Diego Bay survey stations.

A total of 2,033 lobsters were captured in San Diego Bay during the study (2 March - 3 July 1979). Sizes ranged from 47-155 mm in carapace length (C.L.) and averaged 81.5 mm. The sample population consisted of 69% males and 31% females with 42% of the captured lobsters being legal size (82 mm C.L.) or larger. The stock estimate for San Diego Bay was calculated as 17,650 - 21,434 lobsters, depending upon the equation used. This is based upon a 5.3% recapture rate of the 1,699 lobsters tagged and released 2 March - 3 July 1979.

Twenty lobsters were recaptured at stations other than their release sites. No directional pattern was apparent and movement appeared to be entirely random during the study period (i.e., ten moved inward and ten moved outward). Three recaptured lobsters crossed the bay, suggesting that the main ship channel presents no barrier to lobster movements. Female lobsters were five times more likely to move than males, although this appears to be independent of their reproductive condition. Females were at liberty longer and traveled farther than males. The mean distance traveled by all lobsters was 1.7 km with an average of 34 days between captures.

The percentage of ready-to-be-plastered females declined throughout the study at a rate of approximately 10% per month. The percentage of plastered females increased to a peak of 48% in May and declined to 25% in July. Berried females first appeared in June and had increased to 47% by the end of the study in July.

The number of lobsters captured on sampling days varied widely. There were no correlations between the daily lobster capture and water temperature, turbidity, moon phase, or tidal cycles.

Based upon these points and additional data presented in the appendix, there appears to be a tendency for female lobsters to move seaward in late summer and early fall. A well-designed full-year study with concurrent sampling inside and outside of the bay is required to determine if such a pattern exists.

INTRODUCTION

The California spiny lobster (Panulirus interruptus) supports a commercially important fishery which has had annual landings between 190,000 and 398,000 pounds during the 1970's (California Fish and Game, unpublished fishery data 1970-1977). This is relatively small in comparison to the Florida spiny lobster (Panulirus argus) fishery which has reported annual landings of 4-7 million pounds during the same time period (Warner et al., 1977). To provide information for management of the California fishery, several studies of the natural history and population structure have been conducted (Allen, 1916; Lindberg, 1955; Mitchell et al., 1969; and Odemar, et al., 1975).

Mitchell et al. (1969), used scuba to make monthly observations during a 2.5 year study of the lobster population near San Clemente Island, California. These authors found that female lobsters which were "plastered" (i.e., carrying a spermatophore) migrated into shallow water during late March and early April. By the end of April, the majority of females in shallow water were "berried" (i.e., bearing eggs). It was suggested that the females moved to shallow areas because the warmer water hastened egg development. Lindberg (1955) used scuba and trapping methods to study the growth, movement and behavior of lobster populations between Los Angeles Harbor and Palos Verdes Point. It was concluded that there was a general seasonal offshore movement in the fall and winter and an inshore movement in the spring and summer that was observed only with sexually mature individuals. These movements were determined to be more dependent upon sexual condition than size, water temperature, or other oceanographic factors. Lindberg also concluded, from tag returns, that lobster populations are relatively sedentary but become thoroughly mixed by local random movements. Olsson et al. (unpublished report,

1980), conducted a 2-year study of the near-shore lobster population within the San Diego-La Jolla Marine Ecological Preserve. Based upon scuba observations of tagged lobsters along established transect lines, it was found that approximately 40% of the population exhibited a strong tendency to remain in the immediate area. Two-thirds (of the 40%) returned to a particular den after night foraging. Males exhibited a stronger homing tendency and remained in the study area longer than females. Females appeared to move more frequently and greater distances than males (i.e., out of the study area).

In 1977, biologists from the Naval Ocean Systems Center, San Diego, California, conducted a three month trapping survey of the lobster population in San Diego Bay (Peeling, unpublished data, 1977). The results of the survey suggested that female lobsters might move into the Bay during the spring as observed for the lobster population around San Clemente Island.

In January 1979, the Navy began construction of a large pier on the western shore of North Island near the entrance to San Diego Bay. This construction involved dredging and installation of cement pilings and riprap during the period of suspected inward movement of female lobsters. Since mixing occurs between the commercially fished adjacent lobster population and the protected lobsters of San Diego Bay, environmental agencies expressed concern that construction activities might interfere with lobster movements and potentially create an adverse effect on the lobster fishery.

The purpose of this study was to monitor the movements of the San Diego Bay lobster population during the spring and assess the possible impact of pier construction upon the suspected inward movement of lobsters. The data from this study were compared with those of a previous study (Peeling, 1977)

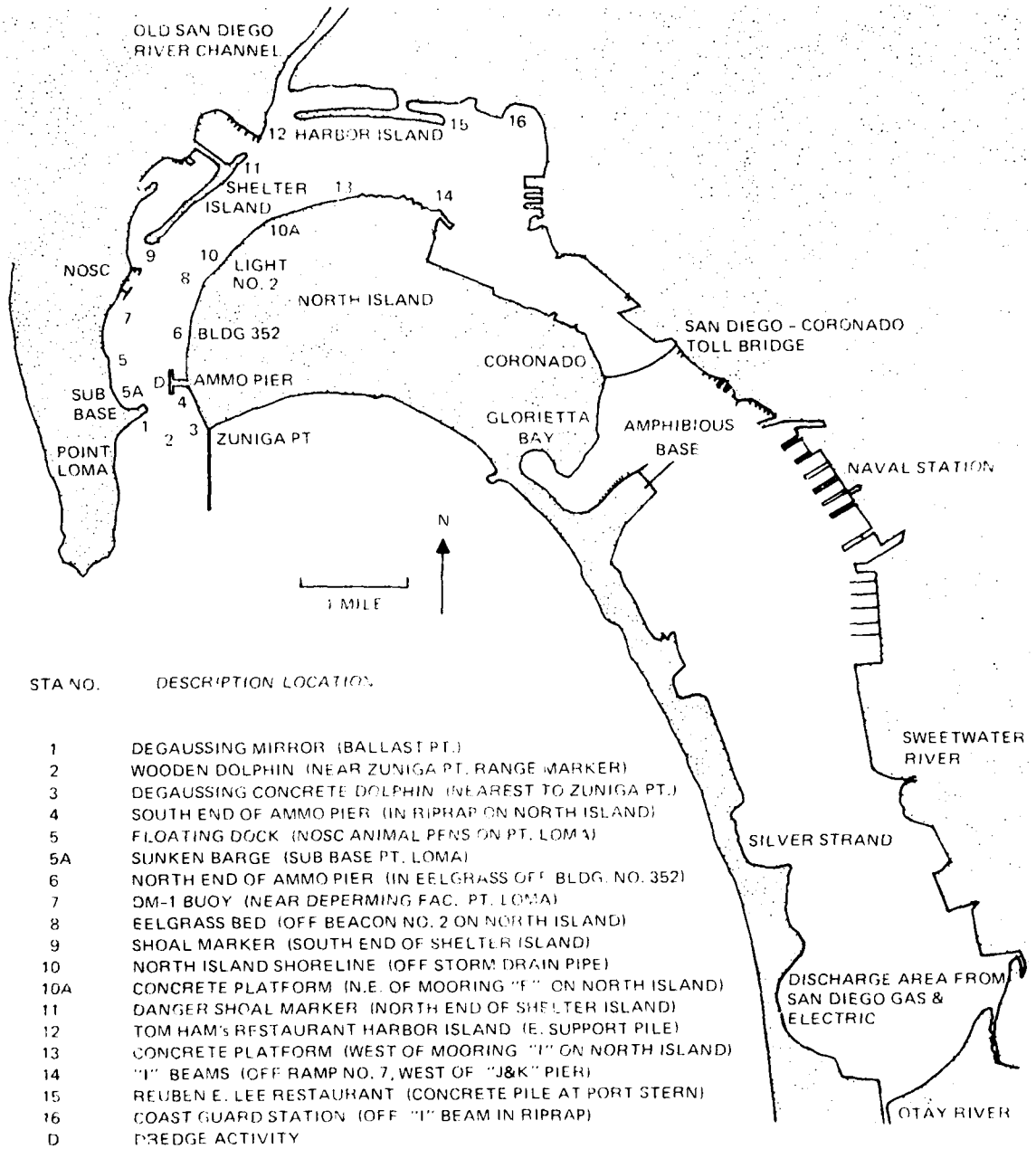
conducted during the same season (i.e., March-June) prior to pier construction. Additionally, these data were used to estimate the size, composition and reproductive cycle of the lobster population in San Diego Bay.

METHODS

Standard commercial lobster traps (i.e., 1.0 m x 1.0 m x 0.4 m with galvanized wire mesh and double entry ports) were placed at sixteen sample stations in San Diego Bay (Figure 1). Eight stations were selected along each side of the main channel to insure that both sides were adequately sampled. Ten of the stations were identical to those used by Peeling (1977) during his lobster survey. Since lobsters are rarely reported south of the Coronado Bridge, no attempt was made to sample this area.

Each trap was baited with four to six Pacific mackerel (Scomber japonicus) and checked twice per week (i.e., Tuesdays and Fridays) from 2 March to 3 July 1979 (Figure 2). The carapace length (C.L.), sex, molt and reproductive conditions were recorded for each lobster. The number of missing appendages and a qualitative rating of the degree of biological fouling were also recorded. Additionally, the surface water temperature was recorded at each station and a 50 ml water sample was collected from the surface and 1 m off the bottom for turbidity determinations.

The carapace length was measured with stainless steel calipers and recorded to the nearest 0.1 mm. The shell condition was classified into four categories, following the nomenclature of Mitchell et al. (1969): (1) old hard shell; (2) old soft shell; (3) new soft shell; and (4) new hard shell. The shell condition and age were assessed by pressing on the carapace to



STA NO.	DESCRIPTION LOCATION
1	DEGAUSSING MIRROR (BALLAST PT.)
2	WOODEN DOLPHIN (NEAR ZUNIGA PT. RANGE MARKER)
3	DEGAUSSING CONCRETE DOLPHIN (NEAREST TO ZUNIGA PT.)
4	SOUTH END OF AMMO PIER (IN RIPRAP ON NORTH ISLAND)
5	FLOATING DOCK (NOSC ANIMAL PENS ON PT. LOMA)
5A	SUNKEN BARGE (SUB BASE PT. LOMA)
6	NORTH END OF AMMO PIER (IN EELGRASS OFF BLDG. NO. 352)
7	OM-1 BUOY (NEAR DEPERMING FAC. PT. LOMA)
8	EELGRASS BED (OFF BEACON NO. 2 ON NORTH ISLAND)
9	SHOAL MARKER (SOUTH END OF SHELTER ISLAND)
10	NORTH ISLAND SHORELINE (OFF STORM DRAIN PIPE)
10A	CONCRETE PLATFORM (N.E. OF MOORING "F" ON NORTH ISLAND)
11	DANGER SHOAL MARKER (NORTH END OF SHELTER ISLAND)
12	TOM HAM's RESTAURANT HARBOR ISLAND (E. SUPPORT PILE)
13	CONCRETE PLATFORM (WEST OF MOORING "I" ON NORTH ISLAND)
14	"I" BEAMS (OFF RAMP NO. 7, WEST OF "J&K" PIER)
15	REUBEN E. LEE RESTAURANT (CONCRETE PILE AT PORT STERN)
16	COAST GUARD STATION (OFF "I" BEAM IN RIPRAP)
D	DREDGE ACTIVITY

Figure 1. Location of sampling stations for lobster study (Mar - July 1979).

Figure 2. Standard [illegible] trap baited with Pacific mackerel.

Figure 3. [illegible] dorsal musculature

determine its hardness and by noting the presence and size of fouling organisms.

The reproductive condition of female lobsters was classified into three categories: (1) ready-to-be-plastered; (2) plastered; and (3) berried. Female lobsters were ready-to-be-plastered; (*i.e., sexually mature*) if the posterior two thoracic sternae were spongy to the touch (Lindberg, 1955). The presence of the spermatophore (plastered) or the egg mass (berried) indicated the reproductive condition of each female lobster. The color of the spermatophore (e.g., white, gray, or black) was noted to provide a qualitative measure of the time elapsed since mating.

Lobsters were tagged with sequentially numbered FL-08 tags[1] inscribed with a phone number and notice of a reward. Each spaghetti tag used a nylon monofilament line and stainless steel T-anchor to secure it to the animal. The tags were inserted into the dorsal musculature between the carapace and first abdominal segment using a syringe needle (Figure 3).

Beaded tags were also used to mark lobsters at the beginning and end of the survey when a supply of spaghetti tags was unavailable. Colored, ceramic beads were threaded onto short lengths of stainless steel suturing wire (24 gauge) following a sequentially numbered color code. These tags were secured to the lobsters by wrapping the wire around the base of the antennae. Approximately one fourth of the lobsters were tagged by this method. A sample of lobsters was tagged by both methods to compare the loss rates of the two tagging methods.

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1. Floy Tag and Manufacturing, Inc., P.O. Box 5357, Seattle, WA 98105

The surface water temperature at each station was measured with a hand-held thermometer and recorded to the nearest 0.2°C. Surface water samples were collected for turbidity analyses by immersing a 50-ml plastic bottle into the water and rinsing it several times before obtaining the sample. A sub-surface water sample was collected within 1 m of the bottom at each station with a Nansen bottle and placed in a 50-ml plastic bottle for subsequent analysis.

Two water samples (surface and subsurface) were also collected within 25 m of the active dredging operations near Station 4 on each sampling date. These samples were used to compare turbidity values near dredge operations with the ambient turbidity values at the other stations.

The water samples were taken back to the laboratory and turbidities determined with a Turner Designs, Model 40-002 Nephelometer. The nephelometer was standardized using a 20 nephelometer turbidity unit (NTU) water standard before each set of measurements. Measurements were recorded to the nearest 0.2 NTU.

RESULTS

A total of 2,033 lobsters were captured, measured and released.[1] These lobsters were composed of 1,400 males (69%) and 633 females (31%). The reproductive conditions of the female lobsters were 246 (39%) ready-to-be-plastered females; 250 (39.5%) plastered females; 60 (9.5%) berried females; and 77 (12%) sexually immature females.

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1. Of these, 334 were released untagged since they were too small (i.e., C.L. <65 mm) to be uniformly sampled with the commercial trap.

Male lobsters had a slightly greater carapace length than females. The mean carapace length for males and females was 82.0 mm and 80.4 mm, respectively. The minimum legal carapace length for the sport and commercial harvest of P. interruptus is 83 mm. In San Diego Bay, which is permanently closed to the commercial lobster fishery (i.e., the use of traps is not permitted in San Diego Bay), 862 (42.4%) of the trapped lobsters measured longer than 83 mm C.L. (75.9% males and 24.1% females). The frequency of legal size lobsters captured in traps remained relatively constant throughout the sampling period (i.e., between 36 and 47%, $\bar{x}$=42%).

Out of 1,699 lobsters tagged, 110 were recaptured. This represented only 89 individuals since 21 males were recaptured twice or more. A total of 74 (83%) males and 15 (17%) females were recaptured. Since females composed 31% of the total lobsters tagged, the incidence of female recaptures was expected to approximate this percentage. However, the actual number of recaptured females was only about half the expected frequency (i.e., 17 versus 31%).

The total number of lobsters trapped, the number of males and females, and the mean surface water temperature and turbidity are summarized for each station in Table 1. Lobsters trapped at Station 15 accounted for 18% of the total survey catch. This station is protected from prevailing winds by a floating restaurant moored to wooden pilings, and the adjacent shoreline is stabilized by large boulders (i.e., riprap) to a depth of several meters which provides an ideal lobster habitat. Only 8% of the lobsters captured at Station 15 were females, well below the mean of 35% (range 19 to 63%) for females captured at the other stations. The reason for this phenomenon is not apparent and we are unable to suggest a possible explanation at this time.

TABLE 1. The total number of Panulirus interruptus captured, percent male and female, surface water temperature, and the surface and subsurface turbidity measurements for each station.

Station	No. Lobsters Captured	Males (%)	Females (%)	Surface Temp (°C)	Surface Turbidity Mean + SD	Subsurface Turbidity Mean + SD
Outer Zone						
1	92	53	47	16.3±2.08	1.4±0.49	1.6±0.63
2	79	44	56	17.5±1.79	1.5±0.62	1.6±0.62
3	126	55	45	16.6±1.90	1.4±0.43	1.7±0.83
Middle Zone						
4	50	48	52	16.7±2.05	1.8±0.53	2.0±0.58
5	59	39	61	17.1±2.20	1.2±0.40	1.3±0.49
6	153	58	48	17.3±1.94	1.7±0.80	1.6±0.55
7	80	59	41	17.4±1.86	1.3±0.34	1.4±0.41
8	145	61	39	17.6±2.34	1.5±0.69	1.5±1.02
9	81	64	36	17.5±1.72	1.4±0.50	2.12±1.24
10	57	63	37	18.9±1.76	1.6±0.36	1.7±0.36
Inner Zone						
11	124	81	19	18.5±2.01	1.6±0.54	2.41±0.92
12	238	79	21	19.0±1.67	1.8±0.89	3.0±1.92
13	12	42	58	18.1±1.42	1.5±0.45	1.8±0.93
14	252	69	31	18.7±1.99	1.8±0.73	2.7±1.36
15	360	92	8	19.0±2.25	1.8±0.55	2.2±1.13
16	139	68	32	18.9±2.14	1.8±1.22	2.5±1.65
Dredge Barge	--	--	--	-- --	1.7±0.88	1.8±0.92
	2,047	x=69%	31%			

Note: Only turbidity was measured at the dredge barge.

REPRODUCTIVE AND MOLT CONDITION

The frequency with which ready-to-be-plastered, plastered and berried females appeared in the semiweekly trap inspections changed during the study period. Table 2 presents the data for female reproductive conditions for each month of the survey. Ready-to-be-plastered females were at their highest value (58%) in March when the study began. Plastered females increased from 31% to 48% and then began to decline as berried females began to appear. A single berried female was captured on 25 April; however, significant numbers did not occur until 1 June 1979. No female lobsters smaller than 67.1 mm C.L. were plastered (i.e., possessed a spermatophore). No female smaller than 70.8 mm C.L. was berried, indicating the minimum size for sexual maturity. No females larger than 106.8 mm C.L. were berried, however female lobsters were plastered up to and including the largest size captured (C.L. = 117.6 mm). Five of the 23 female lobsters (22%) with C.L.'s $\geq$ 100 mm were berried.

All but two lobsters captured during the four month survey had old hard shells. These two were females captured in June and both were classified as having old soft shells.

Female lobsters composed less than 50% of the catch until the last sampling date (3 July) when their relative proportion reached 55%. It is not known whether this trend would have continued. More data are needed to determine the seasonal molt and the complete reproductive cycles of the San Diego Bay lobster population.

TABLE 2. The monthly changes in the sex ratios, reproductive condition, shell condition and number of Panulirus interruptus captured in San Diego Bay 2 March - 3 July 1979.

	March	April	May	June	July*
No. Lobsters Captured	223	473	661	632	4
Males (%)	57	69	77	66	45
Females (%)	43	31	23	34	55
Ready to-be-plastered Females (%)	58	46	36	27	25
Plastered Females (%)	31	43	48	37	25
Berried Females (%)	0	1	0	20	47
Immature Females (%)	11	10	16	16	3
Shell Conditions					
Old Hard Shell (%)	100	100	100	99.7	100
Old Soft Shell (%)	0	0	0	0.3	0
Legal Sized Lobsters (%)	44	47	42	38	36

* Study terminated on 3 July 1979

WATER QUALITY MEASUREMENTS

Water temperature and turbidity were lowest at the outer bay and highest at the inner bay stations. On the basis of temperature and turbidity, the stations were grouped as outer (Stations 1-3); middle (Stations 4-10); and inner (Stations 11-16). A Kruskal-Wallis statistical test (Zar, 1974), performed separately on mean values for temperature, surface turbidity and subsurface turbidity, indicates a significant difference between these station groups ($p > 0.05$).

The mean lobster catch per trap for the entire study was 99 for the outer stations, 89 for the middle stations, and 189 for the inner stations. The number of lobsters captured at the inner stations was approximately twice that of the middle and outer stations. Apparently, the environmental conditions at the inner bay stations (i.e., those with slightly higher temperatures and turbidities) were preferred by the lobsters.

The number of lobsters captured between sampling dates varied widely. Attempts were made to determine if the daily number of lobsters trapped could be correlated with water temperature, turbidity, phases of the moon, or tidal cycles. The data suggest that more lobsters were captured during periods of minimal tidal fluctuations than at other times. However, no tested associations were statistically significant.

EFFECTS OF PIER CONSTRUCTION AND DREDGING ACTIVITIES

The surface and subsurface turbidity measurements taken near the dredging operation were compared to similar measurements taken at the outer, middle and inner station groups (Table 1). Students' t-test (Steel and Torrie, 1960)

indicated mean turbidity measurement values taken near the dredge activities were not significantly different from the same measurement taken at the outer and middle station sets ($p > 0.05$). The mean subsurface turbidity at the inner stations however, was significantly higher than the subsurface turbidity near the dredge ($p \geq 0.05$). These data indicate that dredge operations did not increase the water turbidity above the natural levels recorded at the other stations.

Station 4, located near the center of pier construction and dredging activities, provided only 50 trapped lobsters, compared to 125 trapped at Station 3 (850 m south of Station 4) and 153 at Station 6 (450 m north of Station 4). A chi-square statistical test (Zar, 1974) compared the monthly lobster catch at Station 4 with Stations 3 and 6. The results indicated the monthly lobster catches in the construction areas were significantly lower than at the two nearest stations ($p \geq 0.05$).

Peeling (1977) surveyed the lobster population in San Diego Bay from March through June 1977. We used the same stations as Peeling, including Stations 3, 4 and 6. No construction activities were on-going at these locations during the study in 1977. Therefore, a comparison of the 1977 and 1979 survey data provides an indication of the effects of dredging and construction upon the local lobster population. This comparison is presented in Table 3. Students' t-tests indicate no signficant differences exist between the catches of 1977 and 1979 for stations on either side of the construction site. However, the catches for Station 4 were significantly lower ($p \geq 0.05$) in 1979 than 1977.

TABLE 3. A comparison of lobster catches in 1977 and 1979 at trapping stations near pier construction activities (1977 data, Tom Peeling, 1977).

Station	Year	Number of Sampling Dates (n)	Mean Catch per Sample	Standard Deviation	t-test Results
3	1977	23	4.13	3.96	$t=0.54 (p \geq 0.05)$
	1979	35	3.60	3.47	
4	1977	23	4.66	5.89	$t'=2.57 (p \geq 0.05)$
	1979	34	1.47	1.80	
6	1977	24	3.35	4.07	$t=1.01 (p > 0.05)$
	1979	35	4.37	4.28	

The differences in the catches between Station 4 and Stations 3 and 6, and the differences between the 1977 (before construction) and 1979 data indicate that the effect of pier construction activities upon the lobster population was limited to the immediate construction area (approximately 200 m).

MOVEMENTS

During the study, nineteen lobsters (9 males and 10 females) were recaptured at stations other than their release sites and represented 20 different movements (Table 4).[1] Of 74 recaptured females, 67% moved to another station indicating female lobsters were five times more likely to move than males.

1. One male lobster was recaptured at two different stations.

TABLE 4. The movements of lobsters recaptured in San Diego Bay (2 March - 3 July 1979).

Sex	Carapace Length (mm)	Reproductive Condition	Days at Liberty	Distance Traveled (km)	Direction of Movement
F	75.8	Immature	25	1.3	O
M	80.6	--	11	0.7	I
M	80.6	--	49	6.7	O
M	82.3	--	18	1.8	I
F	73.8	RP	60	1.9	I
M	92.0	--	3	0.6	O
F	89.9	P	33	0.7	O
M	80.8	--	49	0.7	I
M	78.8		42	1.3	O
M	83.4	--	21	0.7	I
F	80.8	RP	53	4.9	I
M	80.4	--	14	0.7	O
M	55.5	--	38	0.9	O
F	101.9	B	4	0.8	O
F	78.0	B	7	4.8	O
F	75.9	P	70	0.8	I
F	77.1	P	31	1.2	I
M	86.4	--	14	0.5	O
F	93.0	P	98	1.7	I
F	92.0	P	48	0.7	I
Mean ($\bar{X}$)	81.96		34.4	1.67	I=10/O=10
F	83.82		42.9	2.05	6 / 4
M	80.08		25.9	1.46	4 / 6

NOTE: RP = Ready-to-be-Plastered
P = Plastered (Spermatophoric)
B = Berried (Ovigerous)
I = Inward (Bayward)
O = Outward (Seaward)

Ten lobsters moved outward toward the entrance to San Diego Bay and ten moved inward toward the inner bay stations. Three of the recaptured lobsters crossed the bay where depths range between 15 and 20 m. The mean distance traveled by recaptured lobsters was 1.7 km (1.05 miles). The maximum distance traveled was by a male (C.L. = 80.6 mm) which moved 6.9 km (4.16 miles) from Station 14 (Coast Guard Station) seaward to Station 7 (Deperming Facility, Pt. Loma). Additionally, this lobster was the only individual recaptured at two stations.

The mean time between release and recapture for all lobsters was 34.4 days. Females were at liberty between captures longer than males (42.9 versus 25.9 days) and traveled farther than males (2.05 versus 1.46 km), however the rate of movement was slightly greater in males (0.056 versus 0.048 km/day). Ninety percent of the females that moved were sexually mature; 70% had already mated while 20% were ready-to-be plastered. This was similar to the frequency of sexual maturity among the total recaptured female population (i.e., 80% mated and 13% ready-to-be plastered).

STOCK ESTIMATES

Tagging and recapturing were conducted concurrently during the four months of this survey. Therefore, equations for stock estimates were used that applied to multiple census techniques. The basic assumptions of the modified Schnabel equation and the Schumacher and Eschmeyer equation are more nearly satisfied than other types of equations reviewed by Ricker (1975). The data used to calculate these equations are presented in Appendix A-1. The modified Schnabel equation for the maximum likelihood of lobster population estimate in San Diego Bay is 17,650 with a 95% confidence interval of 14,374

to 21,666 lobsters. The Schumacher and Eschmeyer equation provides a stock estimate of 21,434 with a 95% confidence interval of 19,202 to 24,254 lobsters. These population estimates do not include lobsters smaller than 65 mm C.L. since lobsters smaller than this could escape through the mesh of the commercial traps used in this survey.

There were 13 lobsters captured during the four months of trapping which had tag scars--equivalent to a tag loss of 11.8%. These losses reduced the total population of tagged lobsters and thus reduced the number of lobsters possible to recapture. This source of error in the stock estimates has been corrected for by multiplying the number of lobsters which could be recaptured at each census date (M_t in Appendix A-1) by 0.882 before the estimates were calculated.

DISCUSSION

REPRODUCTIVE CONDITION

The monthly changes in female reproductive condition observed by Mitchell et al. (1969) for the San Clemente lobster population were different from those observed in the San Diego Bay lobsters. For instance, Mitchell et al. reported ready-to-be-plastered females to appear in January and decline to only 8.7% by May. Plastered females represented 90% of their captured females in April and less than 10% in July. Berried females were first observed by May and increased to a peak of 77.8% in June followed by a rapid decline to 6.8% in August. The monthly changes in female lobster reproductive condition during our study are presented in Table 2. Our data show an increase in plastered females from 31% in March to a peak of 48% in May followed by a decline to 25% in July. The percentage of plastered females in the San Diego

Bay population never approached the 90% level reported for San Clemente Island. Ready-to-be-plastered females declined steadily at the approximate rate of 10% per month throughout the survey from 58% in March to 25% in July. Mitchell et al. found no ready-to-be-plastered females in the San Clemente lobster population during the month of June 1969 at which time, in our survey, they accounted for 20% of the captured females. On the last sample date of our survey in early July, the percentage of berried females had risen to 47%. Based upon data from other studies of the San Diego Bay lobster population (unpublished data 1973-1977, Naval Ocean Systems Center), berried females can be expected throughout the summer months and even into September. The presence of berried females in San Diego Bay has been recorded as early as April and May during other years.

Lindberg (1955), in a classic study of P. interruptus populations near Los Angeles Harbor reported that mating began in November with plastered females most prevalent during March. Berried females were first captured in late April and were observed throughout May, June, July and even August, but not in September. These observations agree more closely with those of the San Diego Bay lobster population than of the San Clemente population.

The lack of agreement between our results and those of Mitchell et al. (1969) could be due to (a) differences in sampling techniques (scuba observations versus trap captures) or (b) differences in the populations sampled (San Clemente Island versus San Diego Bay). Farris et al. (1970) sampled the lobster population in two San Diego coastal areas--their results and observations on the changes in female reproductive conditions also differed from those reported by Mitchell et al. Farris et al. suggest that the observations

made by Mitchell et al. may be related to a steeply sloping rocky bottom condition such as found in the California Channel Islands but not characteristic of the coastal areas.

SEXUAL MATURITY/REPRODUCTIVE SENILITY

Studies of P. argus (Smith, 1951 and Davis, 1975) report that as fishing pressure increases there is a decrease in the average size of females at sexual maturity. Our study found no berried females smaller than 70.8 mm C.L. or larger than 106.8 mm C.L. Though sexual activity (plastered condition) was evident in females down to 67.1 mm C.L. and up to 117.6 mm C.L. (the largest captured), reproductive activity was not. The greatest reproductive activity was seen in females of the 90-95 mm and 95-100 mm C.L. classes. There is some evidence of reproductive senility for females above 106.8 mm C.L. since this was the largest berried female captured. However, if as Lindberg (1955) suggests, larger females are mated later in the season, then they may not have become berried until July or August (i.e., after this study ended). Studies of a fished population of P. argus in Florida (Warner et al., 1977) reported no berried female lobsters smaller than 70 mm C.L. and none larger than 103 mm C.L. The greatest reproductive activity in the P. argus population was observed in the 80-85 mm C.L. size class. Studies of commercially fished populations of P. interruptus in California support our findings of 70 mm as the minimum size for sexual maturity. Odemar et al. (1975) found 90% of the mature females in the lobster population at Santa Catalina Island to have a

C.L. greater than 69 mm. Lindberg's (1955) study of the Palos Verdes lobster population reported sexual maturity for females to occur at a total length of 19-23 cm (approximately 70 mm C.L.).

The mean carapace growth increment for female P. interruptus in the 70-83 mm size range has been determined to be 3.17-3.24 mm/yr (Odemar et al., 1975). Based upon this growth rate it can be seen that the California legal limit of 83 mm C.L. allows for female lobsters to reproduce up to three times before entering the legal fishery. This contrasts with Florida law where the legal limit of 76.2 mm C.L. allows for more limited reproductive activity before harvesting (Gregory et al., 1978).

EFFECTS OF PIER CONSTRUCTION AND DREDGING

The lobster catch at Station 4 (located within the pier construction and dredging site) was significantly less than that at the two nearest stations (Stations 3 and 6). The catch at Station 4 was also significantly lower than it was two years prior to construction activities (Table 3). These results suggest that pier construction reduced the number of lobsters in the immediate vicinity. However, turbidity values were not significantly higher than those measured at other stations within San Diego Bay (Table 2). In one case, a male lobster (C.L. = 78.8 mm) moved outward from the release point in the eelgrass bed on North Island (Station 5), past the dredge and construction activities and was recaptured at the concrete dolphin near Zuniga Pt. (Station 2). Though it cannot be ruled out that this lobster circumvented the construction site by crossing the bay twice, this information provides evidence that the pier construction activities did not present an insurmountable barrier to lobster movements through that area. In addition, female lobsters of

all reproductive conditions were captured in representative numbers within the construction site.

Craig (1973) surveyed the population of spiny lobsters (P. argus) at a sewage outfall construction site in Florida. He found that the lobsters exhibited a tendency to avoid the area "several hundred yards" down-current from the construction site. Craig's findings were similar to ours in that lobsters continued to be trapped in the construction area, but at a lesser rate than at stations outside the immediate construction area.

MOVEMENTS

Lindberg (1955) and Mitchell et al. (1969) reported a general inshore migration of lobsters starting in April and May. These migrations appeared to be associated with increasing water temperature and the presence of a well-developed thermocline. Lindberg's information was based on observations reported to him by others. He tried unsuccessfully to substantiate the migrations by mark and recapture methods. He tagged 2,317 lobsters and recaptured 116 of which 25 lobsters had moved from their release sites. The average distance traveled was 1.0 km and the average period between release and recapture was 87 days (0.01 km/day). There were no patterns to the movements nor any evidence of migration. Lindberg stated that his data indicated "...the existence of a rather sedentary total population thoroughly mixed by random coastwise movements of smaller local populations."

Farris and Bigsby (unpublished manuscript) similarly tagged 4,152 lobsters in September 1969 and 1,430 lobsters in August 1970. With the help of commercial fishermen, they recaptured 1,893 lobsters. The average distance

traveled ranged between 0.01 and 0.62 km per day. They were unable to detect any migration patterns during the fishing season.

Our study found no evidence to suggest that lobsters in San Diego Bay exhibit a directional migration during the spring season. Of the 20 lobsters exhibiting movement, ten moved seaward toward the bay entrance and ten moved bayward (Table 4). The mean distance traveled was 1.7 km after an average 34 days of freedom (0.05 km per day). Our study suggests that the main ship channel presents no barrier to lobster movements. Only 13% of the recaptured males, yet 67% of the recaptured females, moved to another station. Apparently, females were more likely to move than males, a trait possibly related to their reproductive condition (i.e., changing from a plastered to a berried condition). Movements however, were random and no migration pattern could be discerned during the period of the survey. Appendix A-2 is a table showing the data determined from the movements of lobsters recaptured by fishermen in San Diego Bay and the adjacent coastal waters from 3 July to 13 November 1979. These data are included to provide additional information of possible trends in movement patterns, but must be considered as preliminary since the lobsters were captured after the study ended and through unequal sampling efforts in the various capture areas. Based upon this additional data there appears to be a tendency for female lobsters to move seaward in late summer and early fall. More studies are necessary to confirm this observation

Comparing the mean distance traveled by P. interruptus, as given above, with P. argus (a related species with well-documented migratory patterns), provides additional support for the conclusion that P. interruptus exhibits relatively limited movements. Warner et al. (1977) tagged 6,362 P. argus between June 1975 and August 1976 in the Atlantic Ocean and the Gulf of Mexico near Florida. They found that long distance movements in the Gulf were

west-southwesterly and averaged a total distance of 43 km, or 1.4 km per day. Lobsters tagged in the Atlantic moved easterly and westerly and traveled an average of 17 km, or 0.9 km per day. These distances are considerably greater than the distance recorded during our study of the P. interruptus population in San Diego Bay.

STOCK ESTIMATES

The Schumacher and Eschmeyer equation for estimating stocks in San Diego Bay using data from our study was calculated to be 21,434. The modified Schnabel estimate of the lobster population was calculated as 17,650. Since 42.4% of the population is of legal size or larger, the population of legal lobsters in San Diego Bay is 7,484 based on Schnabel estimate. This can be compared directly to the Schnabel estimate of legal-size lobsters reported by Farris and Bigsby (unpublished manuscript). They calculated that there were 13,786 legal-size lobsters in a 32 km long area between Point Loma and La Jolla, California in 1969. They also tagged lobsters in 1970 and calculated the legal-size number to be 11,647, an amount estimated to be conservative.

EFFECTS OF FISHING

Mitchell et al. (1969) used scuba diving techniques to capture 1,553 P. interruptus over a 2.5-year period in the commercially fished waters adjacent to San Clemente Island, California. Farris and Bigsby, using commercial traps similar to those used in our survey, captured 5,582 P. interruptus in fishing areas between Point Loma and La Jolla, California. The effects of fishing are readily apparent when their data are compared to ours from San

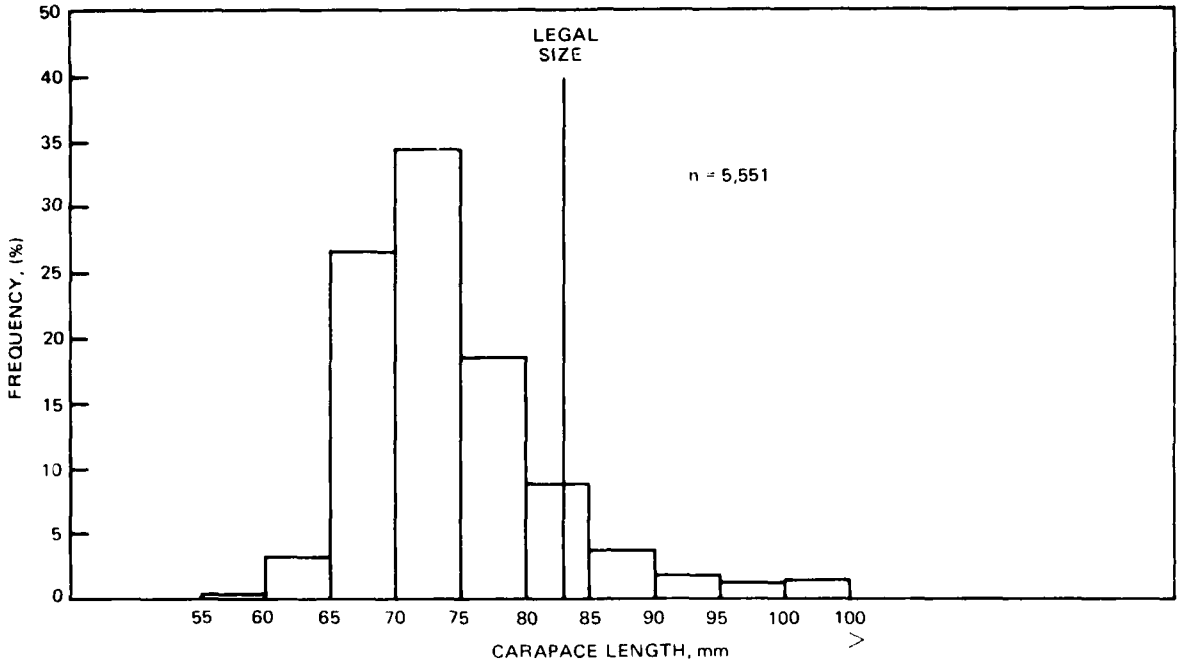

Figure 4. Length-frequency of trap-captured P. interruptus in commercially fished areas off Pt Loma and La Jolla, California (September 1969 and August 1970) (Farris and Bigsby, Unpublished manuscript).

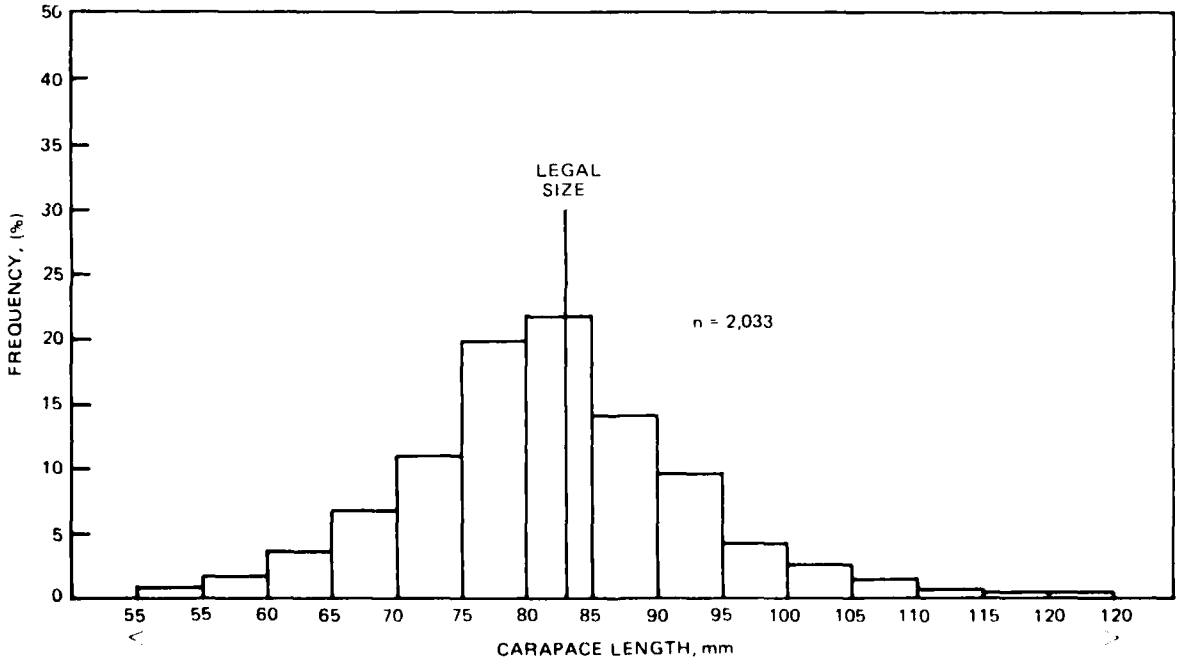

Figure 5. Length-frequency of trap-captured P. interruptus in unfished areas of San Diego Bay, California (March - July 1979).

Diego Bay, where commercial lobster trapping is not permitted. Figure 4 presents a C.L.-frequency histogram produced from the data collected by Farris and Bigsby (unpublished manuscript). Figure 5 shows similar data collected during our study. The histogram from the fished population (Figure 4) is shifted to the left, well below the legal-size limit. The mean C.L. from Farris and Bigsby data was 72.8 mm with 42.4% larger than the legal size limit. Similarly, the lobsters measured by Mitchell et al. (1969) had a mean C.L. of 71.4 mm, 11.8% larger than 83 mm. The effect of fishing appears to cause increased mortality in the sub-legal size classes of spiny lobsters and thus reduces the mean C.L.of the population.

Warner et al. (1977) compared the C.L.-frequency histograms from heavily fished, moderately fished, and unfished populations of P. argus. The legal-size limit for this species is 76.2 mm C.L. and the mean C.L.'s of the three different populations were 72.9 mm (heavily fished), 84.6 mm (moderately fished), and 101 mm (unfished). Their data showed that even in the heavily fished area, 37% of the lobsters were longer than the legal limit. The difference between the fished and unfished histograms and the relatively low percentage of legal-size lobsters in the fished population of P. interruptus when compared to similarly fished populations of P. argus, suggests that large numbers of sub-legal P. interruptus are removed as a result of fishing and/or poaching. Farris and Bigsby (unpublished manuscript) reached a similar conclusion based on the difference in mortality estimates between size classes of lobsters captured off Pt. Loma and La Jolla, California.

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APPENDIX A-1. The data from semiweekly trap inspections used to calculate the Schnabel and Schumacher stock estimate of Panulirus interruptus in San Diego Bay.

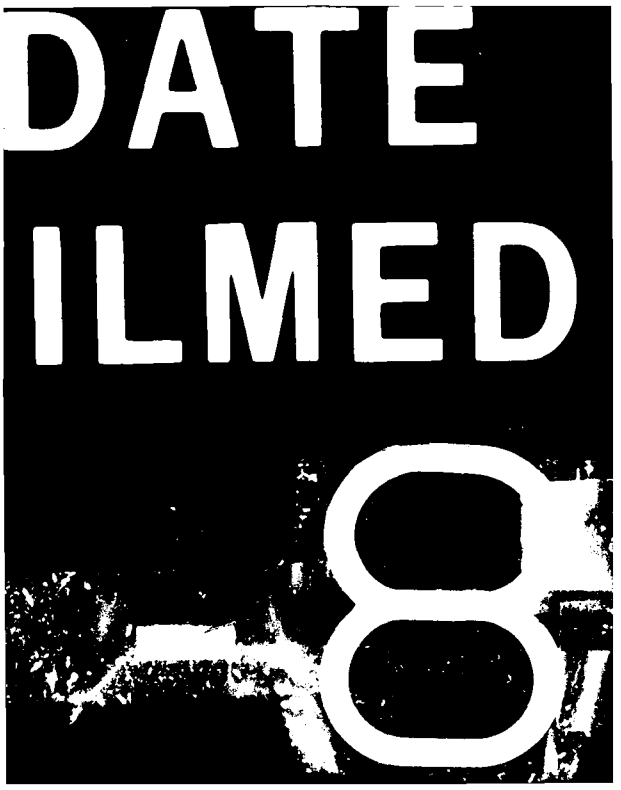
Sampling Date	No. Captured (C_t)	No. Recaptured (R_t)	Marked Lobsters at Large (M_t) [1.]
3-6-79	14	0	0
3-9	30	0	13
3-13	18	0	42
3-16	14	1	57
3-20	35	0	68
3-23	32	0	97
3-27	22	0	123
3-30	59	1	139
4-3-79	48	3	186
4-6	24	2	223
4-10	140	2	241
4-13	68	2	334
4-17	52	2	399
4-20	25	2	446
4-24	47	4	465
4-27	69	2	499
5-1-79	94	7	553
5-4	56	1	628
5-8	67	3	669
5-11	65	5	723
5-15	90	4	772
5-18	72	2	845
5-22	64	2	906
5-25	58	4	957
5-29	94	3	1001
6-1-79	73	6	1073
6-5	54	6	1125
6-8	43	1	1159
6-12	78	5	1192
6-15	50	1	1245
6-19	115	6	1282
6-22	47	2	1368
6-26	86	3	1407
6-29	86	4	1484
7-3-79	58	3	1550
	2,047	89	

1. The numbers in this column are corrected to account for the 11.8% tag loss.

APPENDIX A-2. The movements of lobsters recaptured by fishermen in San Diego Bay and adjacent coastal waters (3 July - 13 November 1979).

Sex	Carapace Length (mm)	Reproductive Condition	Days at Liberty	Distance Traveled (km)	Direction of Movement
F	89.9	B	51	2.3	O
F	80.3	P	26	0.1	O
M	75.0	-	36	1.2	I
M	81.4	-	48	2.3	I
F	71.2	P	35	5.5	O
M	82.5	-	97	1.4	I
F	74.7	RP	167	1.1	O
F	78.5	RP	192	4.9	O
F	74.3	RP	218	11.9	O
M	91.0	-	224	2.0	O
M	96.2	-	229	2.0	O
—	81.36		120.3	3.2	I = 3/O=8
M	85.22		126.8	1.8	3/2
F	78.15		114.8	4.3	O/6

NOTE: RP = Ready-to-be-Plastered
P = Plastered (spermatophoric)
B = Berried (ovigerous)
I = Inward
O = Outward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